ADOPTED FIGURE The figure of Mars used for the computation of the map projection is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3393.4 km and a polar radius of 3375.7 km.

PROJECTION The Mercator projection is used for this sheet, with a scale of 1:5,000,000 at the equator and 1:4,336,000 at lat 30° . Longitudes increase to the west in accordance with usage of the International Astronomical Union (IAU, 1971). Latitudes are areographic (de Vaucouleurs and others, 1973).

CONTROL Planimetric control is provided by photogrammetric triangulation using Mariner 9 pictures (Davies, 1973; Davies and Arthur, 1973) and the radio-tracked position of the spacecraft. The first meridian passes through the crater Airy-O (lat 5.19° S) within the crater Airy. No simple statement is possible for the precision, but local consistency is

MAPPING TECHNIQUE A series of mosaics of Mercator projections of Mariner 9 pictures was

assembled at 1:5,000,000. Shaded relief was copied from the mosaics and portrayed with uniform illumination with the sun to the west, using airbrush techniques described by Inge (1972), and Inge and Bridges (1976). To improve portrayal, various computer enhancements of many pictures besides those in the base mosaic were used. (Computer enhancement of Mariner 9 pictures is described by Levinthal and others, 1973, and Green and others, 1975.) Viking orbiter pictures were also examined and used where they significantly clarified Mariner 9 image data. No attempt was made to portray all information in the Viking pictures, however. Shaded relief analysis and representation were made by Anthony G.

CONTOURS Because Mars has no seas and hence no sea level, the datum (the 0 km contour line) for altitudes is defined by a gravity field described by spherical harmonics of fourth order and fourth degree (Jordan and surface derived from radio-occultation data (Kliore and others, 1973; Christensen, 1975; Wu, 1975, 1978). The contour lines on most of the Mars maps (Wu, 1975, 1978) were

others, 1973), and stereoscopic Mariner 9 television pictures (Wu and Formal analysis of the accuracy of topographic elevation information has not been made. The estimated vertical accuracy of each source of data indicates a probable error of 1-2 km.

compiled from Earth-based radar determinations (Downs and others,

1971; Pettengill and others, 1971) and measurements made by Mariner

9 instrumentation, including the ultraviolet spectrometer (Hord and

NOMENCLATURE All names on this sheet are approved by the International Astronomical Union (IAU, 1974, 1977).

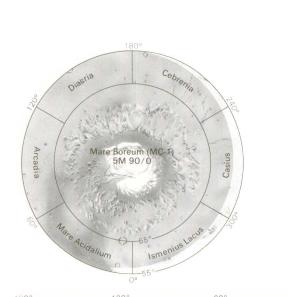
Abbreviation for Mars Chart 16. M 5M −15/158 G: Abbreviation for Mars 1:5,000,000 series; center of sheet, 15°S lat, 158° long; geologic map, G.

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ELYSIUM PLANITIA South Interior-Geological Survey, Reston, Va.-1979-G78437 Prepared on behalf of the Planetary Geology Program Planetary Division, Office of Space Science, National SCALE 1:5 000 000 AT 0° LATITUDE Aeronautics and Space Administration under contract W-13,709 in cooperation with Brown University (NASA MERCATOR PROJECTION grant NGR-40-002-088) 100 50 0 KILOMETERS 100 CONTOUR INTERVAL 1 KILOMETER

Prepared for the NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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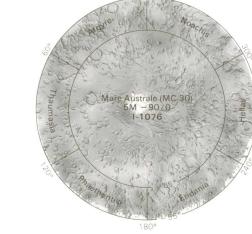
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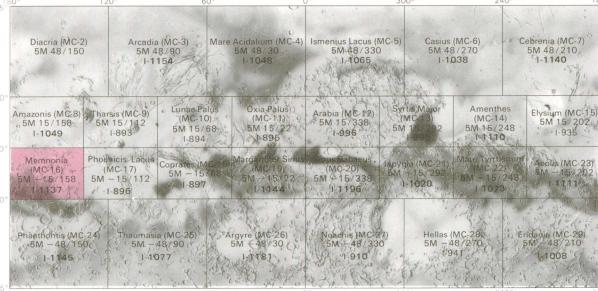
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QUADRANGLE LOCATION Number preceded by I refers to published geologic map

Index No. DAS No. Index No. DAS No. Index No. DAS No. INDEX TO MARINER 9 PICTURES The mosaic used to control the positioning of features on this map was made with the Mariner 9 A-camera pictures outlined above, identified by vertical numbers. Also shown (by solid black rectangles) are the high-resolution

B-camera pictures, identified by italic numbers. Useful coverage is not available in some cross-hatched areas. Pictures other than those shown in the mosaic were used for portraval in the other cross-hatched areas. The DAS

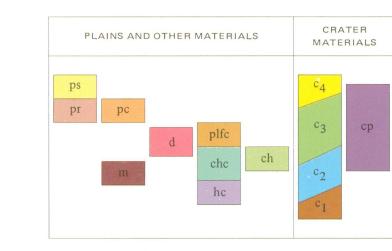
numbers may differ slightly (usually by 5) among various

versions of the same picture.

GEOLOGIC MAP OF THE MEMNONIA QUADRANGLE OF MARS

Thomas A. Mutch and Elliot C. Morris

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

PLAINS AND OTHER MATERIALS ps SMOOTH PLAINS MATERIAL-Occurs over much of the eastern part of the mapped area, in crater floors and some intercrater areas where it forms flat surfaces with relatively low crater densities. Patchy albedo markings common, with dark albedo areas occurring on one side of crater floors. Plains material in craters < 40 km generally not mapped. Type area vicinity of 145°W, 15°S shown in A frame, DAS No. 6894613. Interpretation: Young volcanic flows with a thin covering of eolian sediments, eolian sediment trapped within craters and covering some intercrater areas. Some dark patches may delineate sand dunes ponded against crater walls (Cutts and Smith, 1973) ROLLING PLAINS MATERIAL-Underlies region in northern part of map area. Very similar to cratered plains material in crater density, but has distinctive etched texture, revealed by both topography and albedo visible in A frames. Prominent curvilinear scarps trend approximately northwest. Crater densities highest and surface texture roughest along southern contact with hilly and cratered material. Type area vicinity of 165°W, 5°S shown in A frame, DAS No. 8153913. Interpretation: Relatively thin sequence of volcanic flows mantles older cratered terrain. Distinctive array of mesas, hummocks, and scarps may reflect presence of subjacent structures elsewhere revealed at surface as fretted

CRATERED PLAINS MATERIAL-Underlies eastern part of map area. Surface generally featureless at A-frame resolution except for patchy albedo markings and superposed craters, generally with sharp rims. Southern part of mapped area has relatively large number of degraded craters. B frames reveal numerous irregular scarps, channels, and furrows throughout unit. Has approximately same appearance and age as unit pc mapped by Carr (1975) in the Tharsis quadrangle (MC-9). Type area vicinity of 141°W, 11°S shown in A frame, DAS No. 6894683. Interpretation: Lobate scarps in one B frame are interpreted as lava flow fronts. Proximity to Tharsis volcanic complex further suggests that unit comprises multiple lava flows. Eolian erosion has etched surface, and a discontinuous veneer of sediment causes patchy albedo. Degraded craters in south may be partly covered structures on subjacent cratered terrain DOME MATERIAL-Forms circular dome in floor of crater at lat 19°S, 153°W. Contains a system of orthogonal fractures. Interpretation: Lava lake that has filled a crater and subsequently fractured by contraction or by uplift due to intrusion from beneath after cooling

FRACTURED AND CRATERED PLATEAU MATERIAL-Underlies a region between 155° and 170°W, and 6° and 30°S. Adjoins hilly and cratered material to east and west; boundary gradational, particularly along western contact. Crater densities somewhat lower than type area for hilly and cratered material. Flat intercrater areas more extensive than in hilly and cratered material. Type area vicinity of 157°W, 24°S shown in A frame, DAS No. 8297349. Interpretation: Crater materials that have been partly buried by lavas welling up along tensional fractures in crust CHANNEL MATERIAL-Forms linear to sinuous depressions with terraces, levees, braided channels, and streamlined mesas and hills rising above channel floors. Channels are single channels or constituents of small integrated drainage networks; deeply incised, or anastomosing flat-bottomed channels, nearly at

level of adjacent land surface, covering wide areas. Type locality: Mangala Valles, 151°W, 6°S shown in A frame 8225599. Interpretation: Alluvium in abandoned runoff channels; may include mudflow material. Both depositional CHANNELED AND CRATERED MATERIAL-Underlies a region between 145° and 154°W, and 5° and 18°S. Gradational with hilly and cratered material to west. Traversed by numerous channels, including Mangala Valles. Surface blotchy, albedo variable. Individual craters characterized by gently rolling topography. Rim deposits generally lacking, as are sharp breaks in slope at top and ttom of crater walls. Type area in vicinity of 150°W, 8°S shown in southern two-thirds of A frame, DAS No. 6822793. Interpretation: Crater materials that have been altered and redistributed by action of ground water and surface

MOUNTAIN MATERIAL-Forms belt of mountains approximately 400 km long comprising en echelon ridges with hummocky texture. Type area vicinity of 147°W, 15°S shown in western part of A frame, DAS No. 6894613. Interpretation: Formed by compressional deformation of preexisting crater material HILLY AND CRATERED MATERIAL—Underlies west and east part of map area. Fresh and degraded crater densities are among highest on Mars (figs. 1 and 2). Most craters lack recognizable rim deposits and are partly filled with smooth plains material (unit ps), which imparts a flat appearance to landscape, high crater densities notwithstanding. Widely spaced escarpments trend generally north-south. Furrowed texture locally well developed, as in vicinity of 178°W, 19°S. Eastward, landscape becomes smoother and crater densities decrease. Type area for unit is 173°W, 17°S, A frame, DAS No. 6678733. *Interpretation*: Produced almost exclusively by impact processes and consists mostly of interlayered breccias. Some flat intercrater regions may be volcanic. If so, volcanic blanketing increases in importance eastward

CRATER MATERIALS Craters are classified according to relative age on the basis of their morphologic characteristics. Craters less than 25 km diameter were not mapped. Most craters in the following categories are believed to be of impact origin MATERIALS OF SHARP-RIMMED CRATERS-Rims complete, raised and clearly identifiable hummocky rim material extending at least one crater diameter from center of crater. Central peaks present and conspicuous MATERIALS OF RIMMED CRATERS-Rims complete, raised and rough appearing where diameter is > 30 km. Floors generally lower than adjacent terrain; rough in craters < 30 km, otherwise bowl shaped. Central peaks present and MATERIAL OF SUBDUED CRATERS-Rims similar to c₃ craters but generally have narrow, smooth walls. Floors smooth, flat, lower than adjacent terrain. Central peaks small or absent MATERIAL OF HIGHLY DEGRADED CRATERS-Rims incomplete; consist in

large part of rough material. Floors like those of c₂ craters but about same elevation as adjacent terrain. Central peaks absent CENTRAL PEAK MATERIAL-Prominent hill near centers of c4, c3 age craters and some c₂ age craters. *Interpretation*: Brecciated crater floor uplifted by rebound during shock decompression following compressive stage of impact

Fault scarp—Ball on low side. On narrow graben ball either centered between or

Scarp-Line at base, barb points downdip. In places represents contact Ridge

Crater rimcrest-Not shown around smaller craters or where indistinct



FIGURE 1.—Distribution of all fresh craters greater than 4 km in diameter. Isolines were generated by measuring crater densities within a 10° diameter search circle moved around the quadrangle on 1° centers. Shading increases in density from few craters (light) to abundant craters (dark).

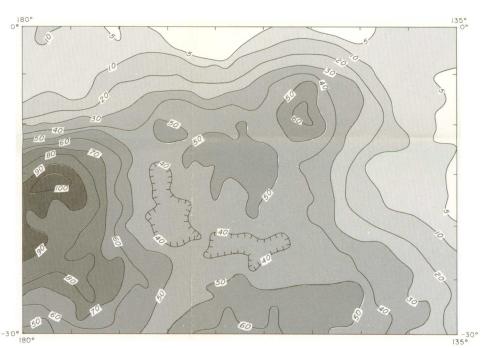


FIGURE 2.—Distribution of all degraded craters. Isolines were generated by measuring crater densities within the 10° diameter search circle moved around the quadrangle on 1° centers. Shading increases in density from few craters (light) to abundant

PHYSIOGRAPHIC SETTING

The Memnonia quadrangle lies astride the boundary between heavily cratered and sparsely cratered hemispheres of Mars (Carr and others, 1973). Densely cratered terrain occurs in the southwestern part of the quadrangle. Strips of plains material bound the cratered terrain in both the northern and eastern parts of the quadrangle. There is approximately 3 km of relief across the quadrangle, with the highest elevations in the eastern part. Plains materials of this region are situated along the lower slopes of the Tharsis Montes, which continue to rise in elevation eastward into the adjacent Phoenicis Lacus and Tharsis quadrangles. There is little correlation between terrain type and elevation within the Memnonia quadrangle. In particular, the boundary between cratered terrain and plains for the most part is not marked by any prominent change in elevation. Several remarkable landforms occur in this area. Mangala Valles, channels that show evidence of erosion by running water (Milton, 1973), occur in the northeast quadrant. Several other channels of similar form appear in the same region. A great system of faults, Memnonia Fossae, trends southwest across the southeast quadrant. These faults are part of a fracture system that radiates outward from the Tharsis uplift (Carr, 1974) and is visible across an entire hemisphere of Mars.

GEOLOGIC SUMMARY The oldest material in the area is hilly and cratered material. Crater densities here are among the highest anywhere on the planet, both for fresh and degraded craters. Maximum densities occur along the west margin of the quadrangle (figs. 1 and 2). The abundance of craters suggests that this region of Mars has been modified predominantly by impact processes. However, there is some evidence for subordinate volcano-tectonic activity. Discontinuous, irregular scarps trend north-south at widely spaced localities. Smaller, closely spaced furrows are locally abundant, generally trending toward the northeast. Flat intercrater surfaces are present, especially in the eastern part of the map region. These might be of volcanic origin (Wilhelms, 1974), although decisive evidence is lacking. Within the mapped region of hilly and cratered material are several coalescing and irregular craters that may be volcanic calderas. The best example is that at 156°W, 27°S where an irregular depression comprises three or four coalescing circular structures. The southernmost member contains a concentrically disposed interior crater. This pattern of nested circular depressions is observed in terrestrial calderas that have undergone multiple phases of extrusion and collapse.

Along the east margin of the hilly and cratered material and in the central part of the quadrangle, the terrain consists of two distinctive types of altered material: channeled and cratered material, and fractured and cratered plateau material. In the region of channeled and cratered material, many individual craters are characterized by gentle frying-pan forms with flat floors and steep narrow walls. Rim deposits are generally absent, as are sharp breaks in slope at the top and bottom of crater walls. The surface has a blotchy appearance. An important clue to the origin of channeled and cratered material is provided by the channels in the same area. The most prominent channels, Mangala Valles, have a braided pattern, which suggests the former presence of flowing water. Sharp and Malin (1975) suggest that Mangala Valles are outflow channels nourished by ground water that seeped upward to the surface and that may have formed a substantial reservoir in a region at the south end of the channels. They speculate that there was catastrophic outflow from the reservoir, perhaps analogous to the floods of eastern Washington that followed the sudden release of water from Pleistocene lakes located in western Montana. These floodwaters scoured lava plains to form a distinctive terrain known as the channeled scabland (Bretz, 1923). The anastomosing and braided character of Mangala Valles resembles channels of the scablands. The presumed surface reservoir was located in a region now composed of hummocks and numerous small channels and irregular scarps.

Accepting this model for the formation of Mangala Valles, it is reasonable to postulate that the region underlain by channeled and cratered material has been affected by groundwater seepage and surface runoff. The water content may have reduced the viscosity of the regolith and favored the elimination or smoothing of original topographic irregularities, especially crater rim deposits, sharp rim crests, and steep crater walls. The second region of altered material is termed fractured and cratered plateau material. It occurs in the vicinity of the Memnonia Fossae, a set of great tensional fractures that extend more than 1000 km along strike and 500 km across strike throughout the central part of the quadrangle. This area is characterized by large flat, intercrater surfaces. Probably these surfaces are depositional in origin, formed by the emplacement of lava that welled up along vertical fractures in the crust. The association of faulting and volcanism is supported by the presence of a crater with cracked floor materials (unit d) at 153°W, 19°S. The texture of these materials suggests a large lava lake that has been ruptured during post-consolidation readjustments. The crater is intersected by a major tension fault, which may have provided a pathway for ascending magma.

The three varieties of cratered terrain described above are bounded by plains materials to the north and east. The contact characteristically is sharp; cratered materials locally stand higher than plains, and the two terrains are separated by an escarpment. As the contact is traced westward through the Aeolis quadrangle (MC-23), erosional dissection of cratered terrain gives rise to a wafflelike complex of mesas and knobs, termed fretted terrain by Sharp (1973). In the Memnonia quadrangle, transgressive overlap of plains materials may have buried the fringing erosional remnants of cratered terrain. Plains materials have been divided into three map units: cratered plains material, rolling plains material, and smooth plains material. The cratered plains and rolling plains probably share a volcanic origin, and they may well be of the same age. The differences are related to surface markings and, perhaps, to obscuration of the surface by atmospheric dust. Within the cratered plains, B-frame pictures reveal the presence of lobate scarps, very similar to forms previously recognized on lunar mare surfaces. On both the Moon and Mars, they can be safely interpreted as lava flow fronts. The rolling plains material displays a variety of landforms: mesas, hummocks, knobs, scarps, and furrows that suggest the presence of cratered terrain beneath a relatively thin veneer of volcanic flows. Smooth plains materials show a few small superposed craters with sharp rim crests. It is possible that the actual surface is hidden below a pall of atmospheric dust. Eastward into the Phoenicis Lacus quadrangle (Masursky and others, 1978), older plains units can be differentiated beneath the eolian cover of this smooth plains.

AGE DETERMINATIONS The relative ages of the various geologic units and structures described above can be fairly confidently determined by direct observation and inference. Absolute ages are much more uncertain. Hilly and cratered material is the oldest. This material was formed almost exclusively by impact brecciation during the terminal stage of planetary accretion and intense bombardment. By analogy with the ified, are overlapped by plains materials. A precise determination of crater densities, and therefore absolute ages, for the cratered plains is difficult for several reasons. Eolian erosion has variably modified plains materials, destroying some of the smaller craters. Atmospheric dust in some pictures obscures surface detail. Some of the larger craters may have formed an old surface that has been partly covered by plains materials. Putting all these uncertainties to one side, an approximate age for the cratered plains, based on a model that equates lunar and martian cratering rates (Soderblom and others, 1974), is 1 b.y. or less. Channeled and cratered material and fractured and cratered plateau material must be bracketed in age by hilly and cratered material and cratered plains material, as they were formed by modification of the former materials and are overlapped by the latter materials. Accordingly, they probably formed

in the interval 3.5 to 1.0 b.y. ago. There is presently no way of directly determining an age for the fluvial erosion that characterizes channeled and cratered material. It should be noted that Mangala Valles superficially appear to empty onto the rolling plains. Close examination, however, reveals no trace of a channel or sediment fan superposed on plains materials. Instead, the channel appears overlapped by plains material and, consequently, must have an age in excess of 1 b.y. For this reason, short-term variations, such as those postulated by Ward (1973), are an unlikely mechanism for the fluvial activity. Longer term periodic changes in climate are possible (Hartmann, 1974), but highly speculative. The model favored here involves accretionary degassing, with formation of a dense atmosphere (Fanale, 1971). Subsequent cooling led to precipitation of water, percolation into the regolith, formation of ground ice, and catastrophic failure of ice-capped underground reservoirs. Both Chapman (1974) and Jones (1974) have presented evidence from crater distributions for an ancient planetwide degradational event. An absolute age is undetermined. However, generation and subsequent cooling of a primitive atmosphere, accompanied by fluvial activity as described above, probably would have been completed in the first third of martian history. Accordingly, channeled and cratered material is probably only slightly younger than hilly and cratered material.

Fractured and cratered plateau material is characterized by numerous tensional faults. Although some of these faults also transect cratered plains, most are overlapped by younger plains materials. This relation is most clearly demonstrated by several islands of hilly and cratered material that are completely surrounded by unfractured plains. Carr (1974) estimates that the fracturing reached a maximum about 1.2 b.y. ago. Phillips and Saunders (1975) estimate that the uplift and fracturing of the Tharsis plateau occurred sometime between 1 and 3 b.y. ago. Both of these estimates indicate that the fracturing is more recent than the fluvial erosion that characterizes the channeled and cratered material. It is reasonable to assume that the time of major fracturing was also the time of major volcanic activity responsible for the formation of flat intercrater areas in fractured and cratered plateau material. Accordingly, the materials of this unit are younger than the channeled and cratered

Mountain material forms massive, en echelon ridges that are clearly older than the overlapping plains materials. They also appear older than the tension faults, one of which forms the southern boundary to the mountain area. The ridges do not resemble the angular peaks that surround some martian impact basins, notably the Isidis Basin (Syrtis Major quadrangle). In the absence of any more persuasive correlation, they are assigned to a period of structural deformation early in the formation of the Tharsis uplift. Accordingly, their age is slightly greater than that for the tension faults. WIND PATTERNS

The most recent geologic activity is wind erosion and deposition. Sediment has pended in larger craters where it forms smooth plains material. Dark blotches on the downwind side of crater interiors probably are fields of sand dunes (Cutts and Smith, 1973). Both bright and dark streaks occur in the lee of sharp-rimmed craters (fig. 3). Bright streaks trend generally toward the southeast, and dark streaks toward the south. REFERENCES

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FIGURE 3.-Distribution and orientation of bright (circle) and dark (dot) wind streaks formed on the downwind side of craters.